Studying Photon Structure at Electron-Ion-Collider

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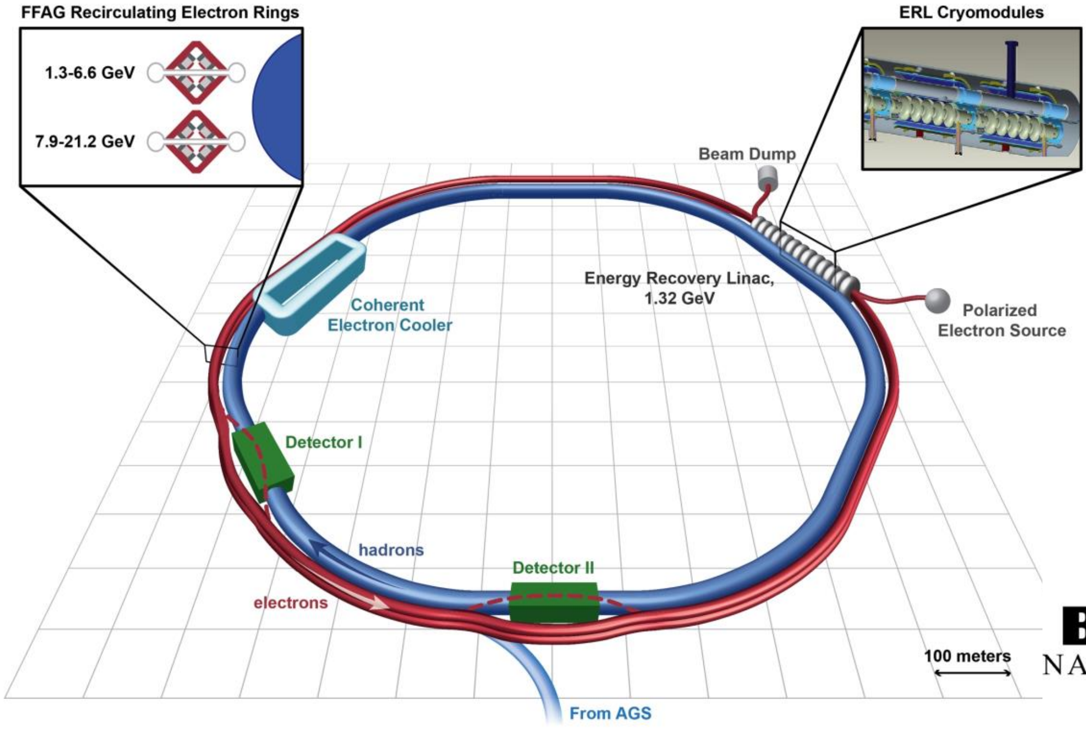
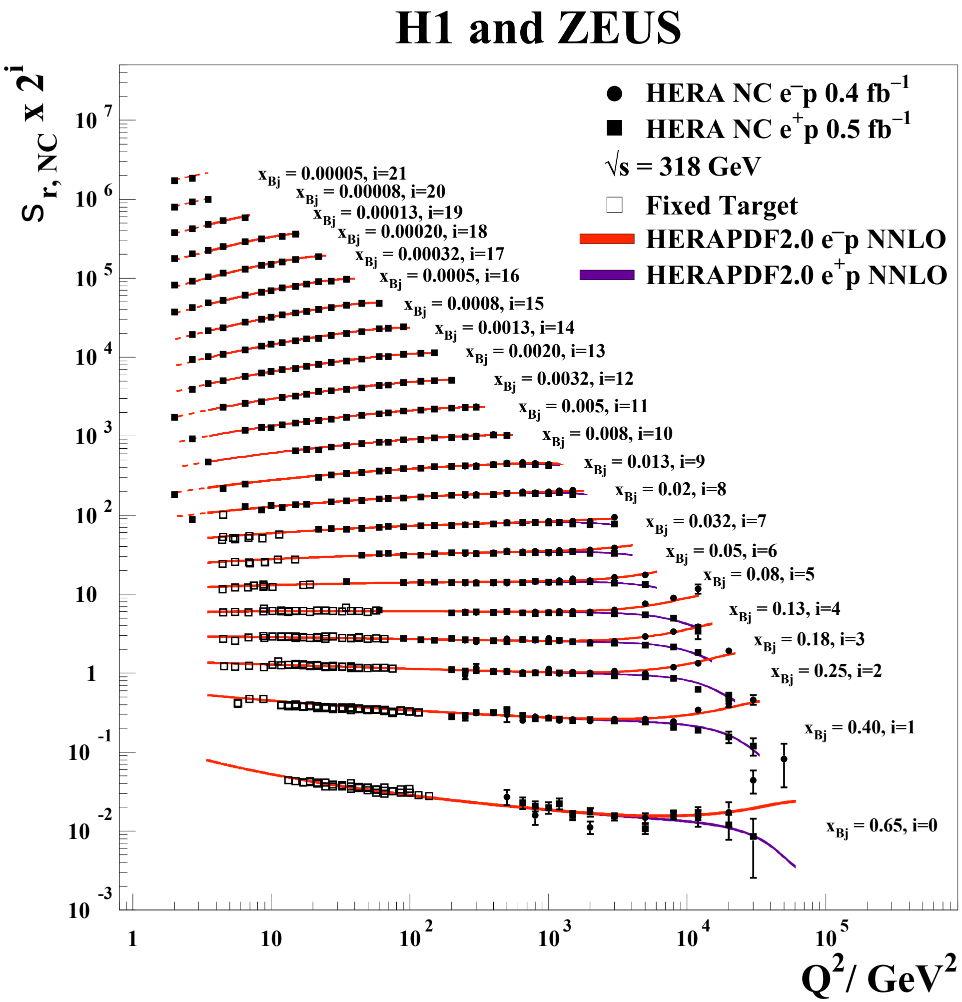


Outline

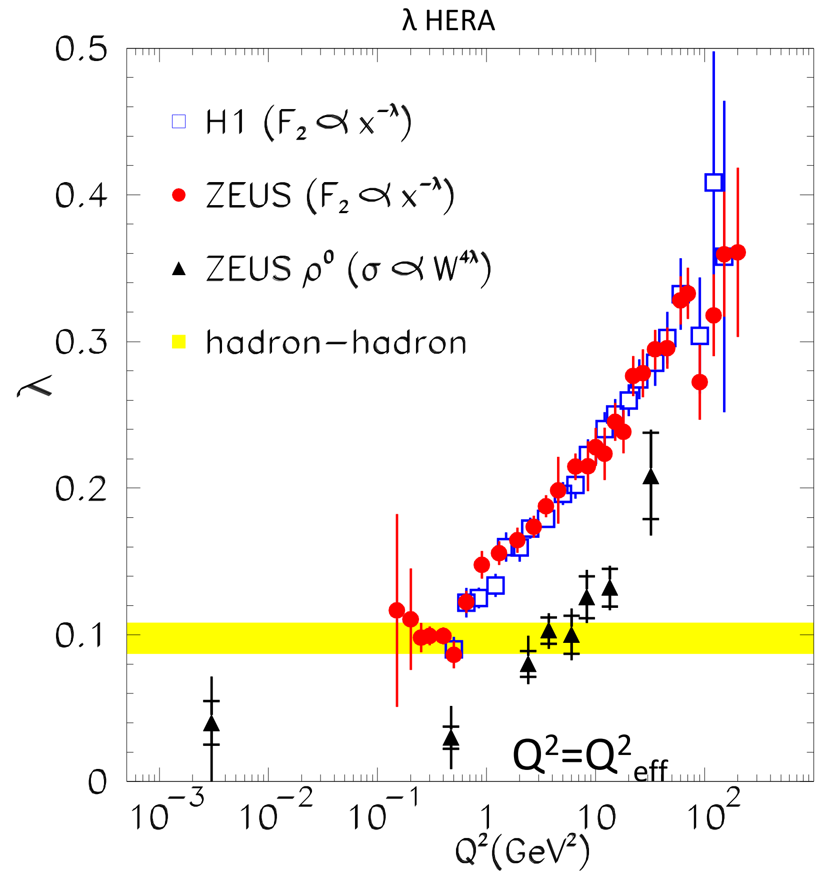
- **Introduction**
- **Photon structure at EIC**
  - Di-jet & Di-hadron method
  - Validating Monte Carlo with HERA data
  - Separation of direct and resolved process
  - Reconstruct $\boldsymbol{x_\gamma}$
  - Jets from photon side & jets from proton side
- **Summary**

Problem?

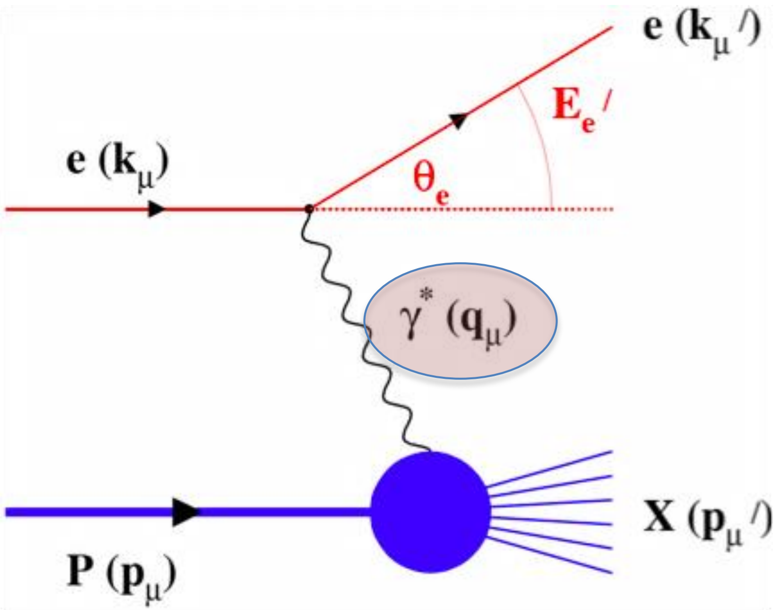


$q(x,Q^2)+\bar{q}(x,Q^2)$ $\quad$ $g(x,Q^2)$ $\quad$ $q(x,Q^2)-\bar{q}(x,Q^2)$

$$\frac{d^2\sigma^{NC}_{e^{\mp}p}}{dxdQ^2} = \frac{2\pi\alpha^2_{em}Y_+}{xQ^4}\left(F_2 - \frac{y^2}{Y_+}F_L \pm \frac{Y_-}{Y_+}xF_3\right)$$



Introduction



- Behavior of the exchanged photon:
  - ➢ Bare photon state
  - ➢ **Hadronic photon state**

Photon can be superposition of above states!

- The "internal structure" of photons is a manifestation of **quantum fluctuations**
  - ➢ Photon splits into parton content $(t \gg E/M^2)$
- We measure the photon structure in quasi-real photoproduction
  - ➢ Low Q^2 events

Structure of the photon

- **Unpolarized photon structure:**

arXiv:9504004, arXiv:9710018, Eur. Phys. J. C 10, 363{372 (1999), DESY 97-164

- **Polarized photon structure: (critical input for ILC $\gamma\gamma$ option)**

no data

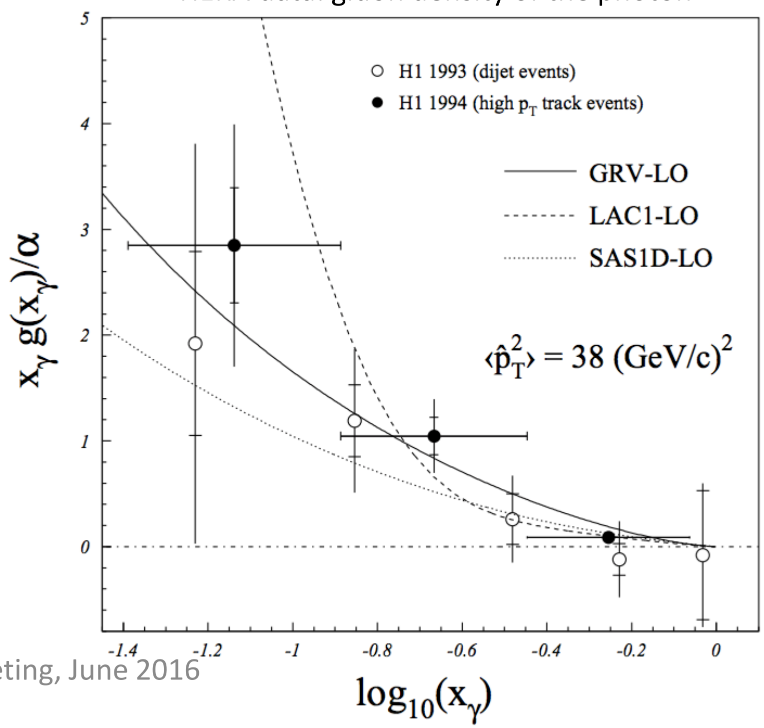
theory: Z. Phys. C 74, 641—650 (1997) and arXiv:971125

- **Photon Parton Distribution Functions(PDFs)**
  - Density of the partons
  - With large uncertainty

$$f(x,Q^2)\left\{\begin{array}{l} q(x,Q^2) \\ \bar{q}(x,Q^2) \\ g(x,Q^2) \end{array}\right.$$

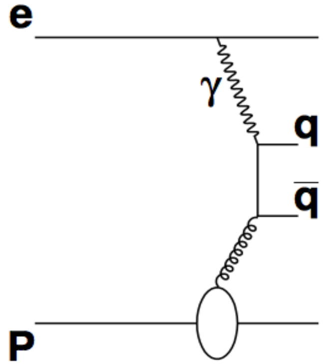
- x_γ is defined as the momentum fraction of the parton from the photon

HERA data: gluon density of the photon



Resolved/direct process

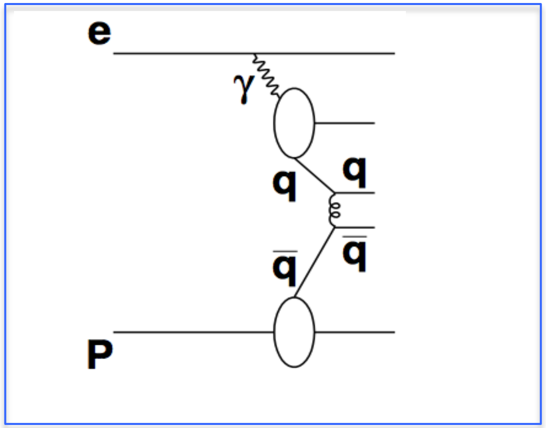
- "**Direct process**" **category**
  - ➢ Point-like photon(no substructure)
  - ➢ x_γ is close to 1



PGF: Di-jet produced

- "**Resolved process**" **category**
  - ➢ Hadronic photon
  - ➢ x_γ is smaller than 1
  - ➢ Di-jet/di-hadron production

➔ Separate di-jet(di-hadron) produced in resolved and direct processes, to get clear resolved process.



Similar with pp collision

Di-jet / Di-hadron method

- **Di-hadron method**
  - Two hadrons with highest p_T

- **Di-jet method**
  - Two jets with highest p_T

Reconstruct x_γ by using di-jet/di-hadron as observables:

$$x_g^{rec} = \frac{1}{2E_e y}\left(p_{T1}e^{-\eta_1} + p_{T2}e^{-\eta_2}\right)$$

- **Parton densities in the photon can be extracted by measuring di-jet cross section**

PYTHIA simulation confronted with HERA data

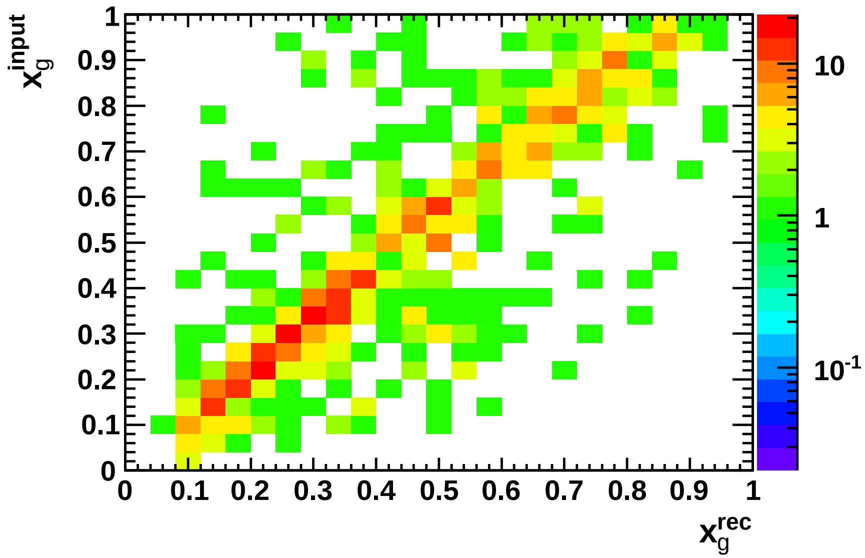
Kinematics cuts from HERA:

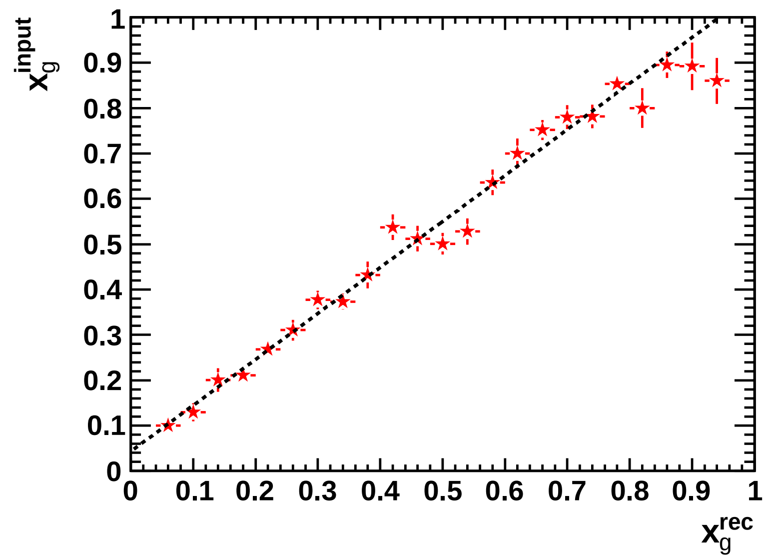
27GeV×820GeV

$0.2<y<0.83$

E^{jet1}_T, $E^{jet2}_T>7.5$ GeV , $E^{jet1}_T+E^{jet2}_T>20$GeV, $|E^{jet1}_T-E^{jet2}_T|/(E^{jet1}_T+E^{jet2}_T)<0.25$

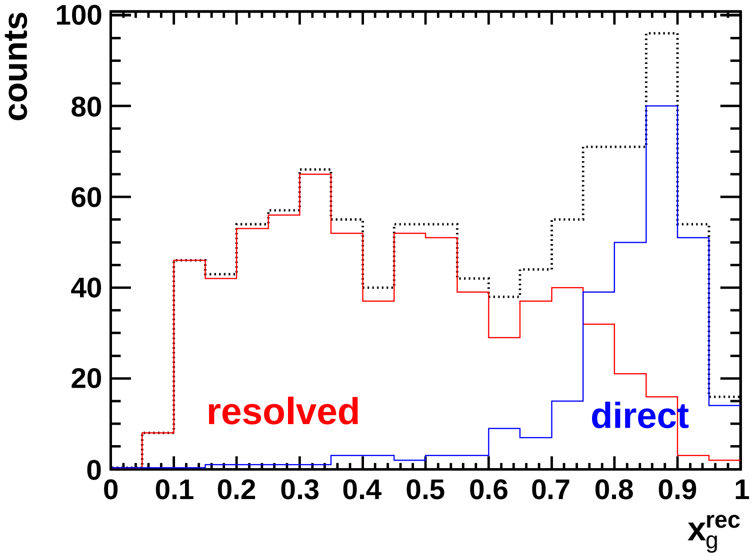
$|\Delta\eta^{jets}|<1$, $0<\eta^{jet1}+\eta^{jet2}<4$

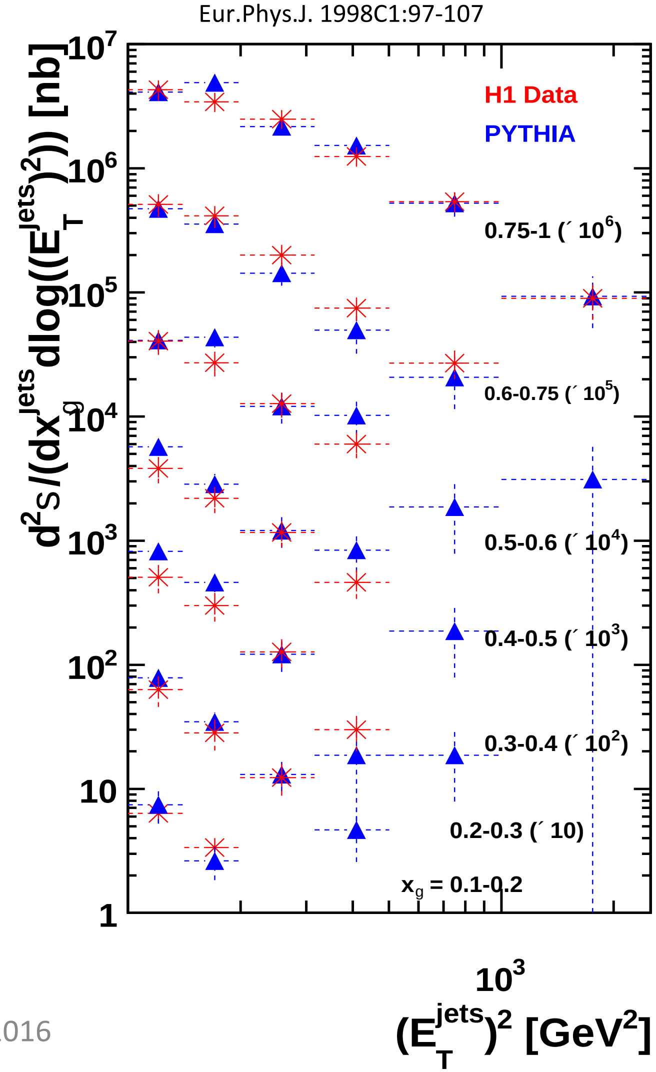




- Strong correlation observed between x_γ^{rec} and the input x_γ^{input} used in the simulation indicates the di-jet observation is an excellent tool for x_γ^{rec} reconstruction.

PYTHIA simulation confronted with HERA data

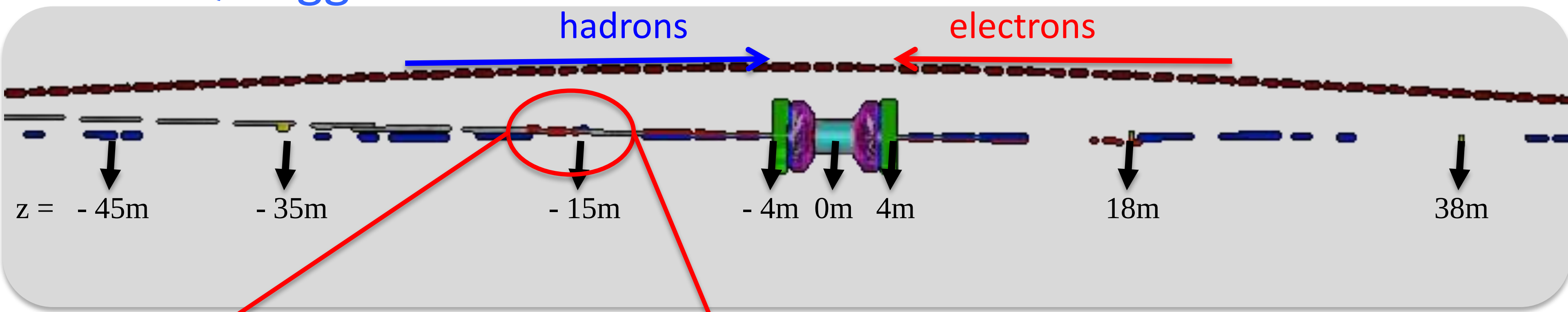




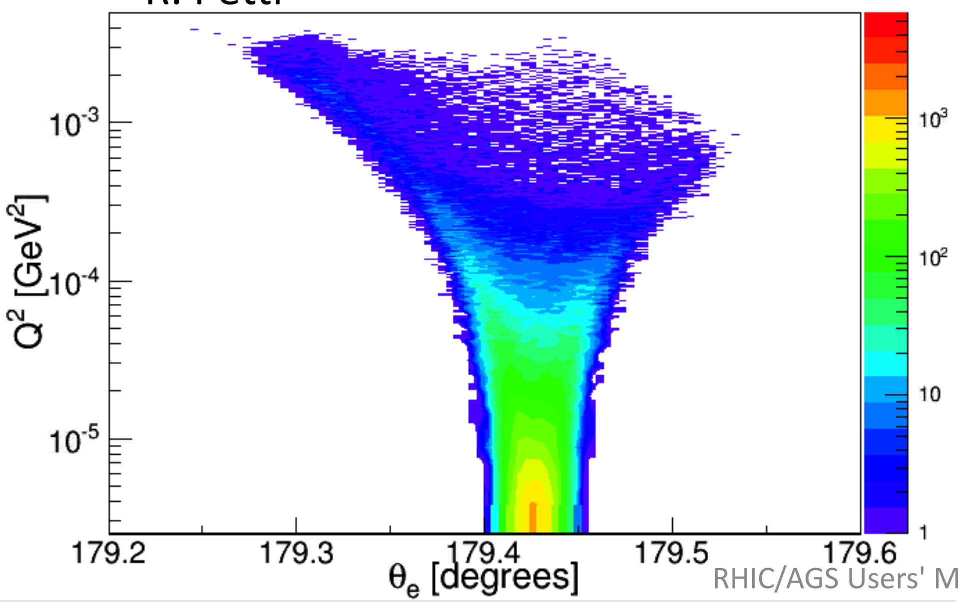
- Reconstructing x^{rec}_{γ} provides a good way to separate direct/resolved contribution(x^{rec}_{γ}< 0.75)
- Our simulation can match the existing data perfectly

EIC Advantages

- Low Q^2 tagger



R. Petti



- pythia events with electron reconstructed in the tagger
- acceptance for electrons down to Q^2~$1x10^{-5}$ GeV^2

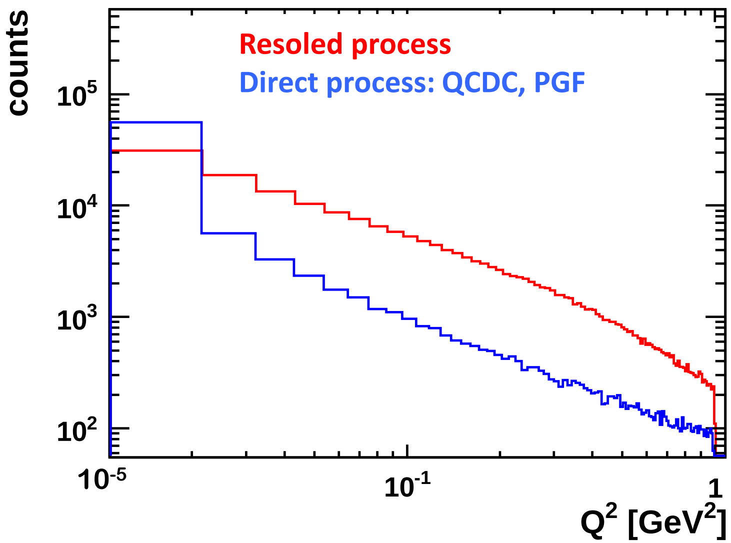
Photon structure at EIC

- Statistic description
  1. Basic parameters

Parameter	Set
Ee	20 GeV
Ep	250 GeV
Q^2	< 1
x	10^{-9} — 0.99
Proton PDF set	CTEQ5
N_{evt}(million)	25
σ (microbarn)	54.7
$L_{int}(pb^{-1})$	0.457

CTEQ5 shows the best description of cross section at low Q^2

2. Di-jet produced in ep collision through hard scattering



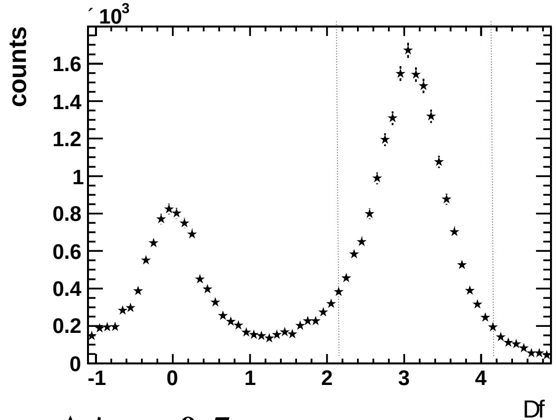
Resolved process
qq → qq
q qbar → q qbar
q qbar → gg
gq(qg) → gq(qg)
gg → q qbar
gg → gg
79%

Direct process: QCDC, PFG
$\gamma_T q \rightarrow qg$
$\gamma_L q \rightarrow qg$
$\gamma_T g \rightarrow q\,qbar$
$\gamma_L g \rightarrow q\,qbar$
21%

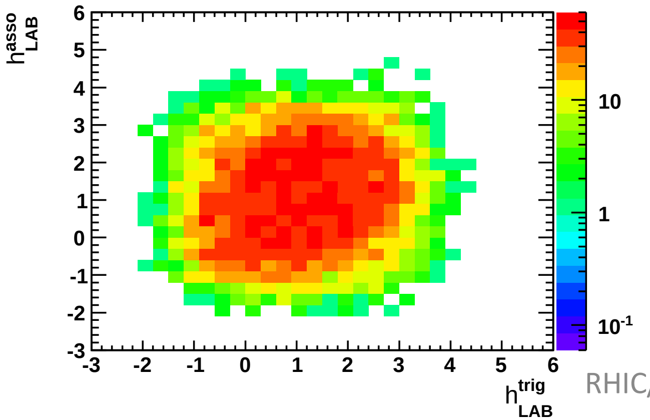
Kinematics cuts for di-hadron/di-jet methods

Di-hadron cut:

1. Two highest $p_{T,}$ p_T^{trig}>2GeV, p_T^{asso}>1GeV
2. π/K/p

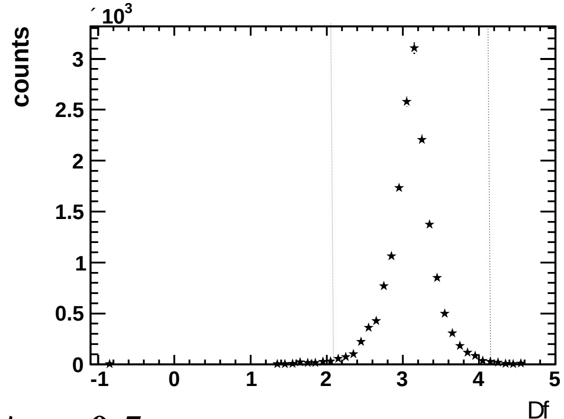


1. $\cos\Delta\phi < -0.5$

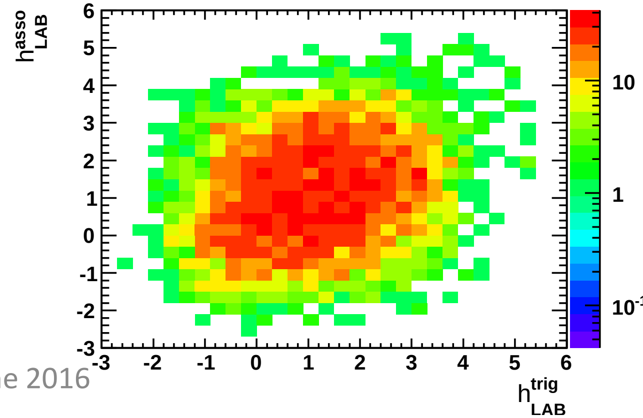


Di-jet cut:

1. Two highest p_T, p_T^{trig}>5GeV, p_T^{asso}>4.5GeV
2. Inside the jet, stable particle p_T>250MeV

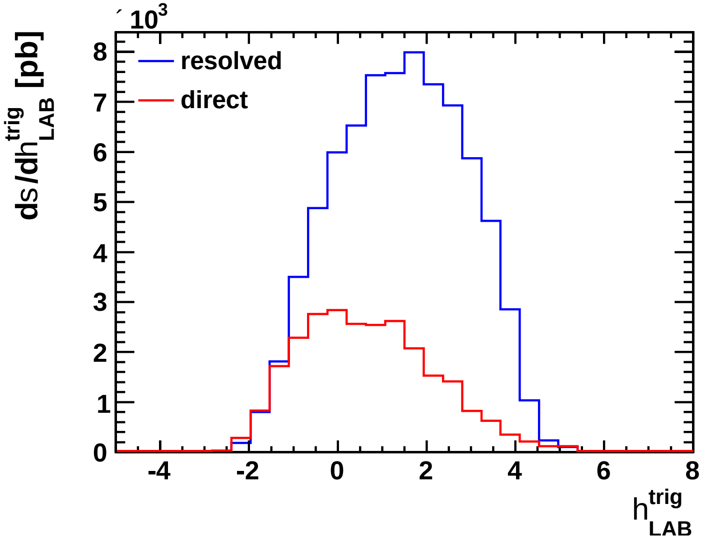


1. $\cos\Delta\phi < -0.5$

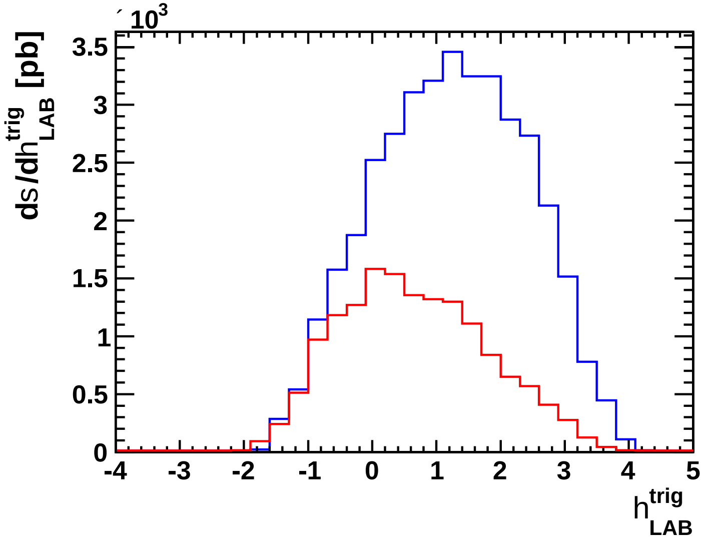


η_{LAB} separation

Di-hadron method



Di-jet method

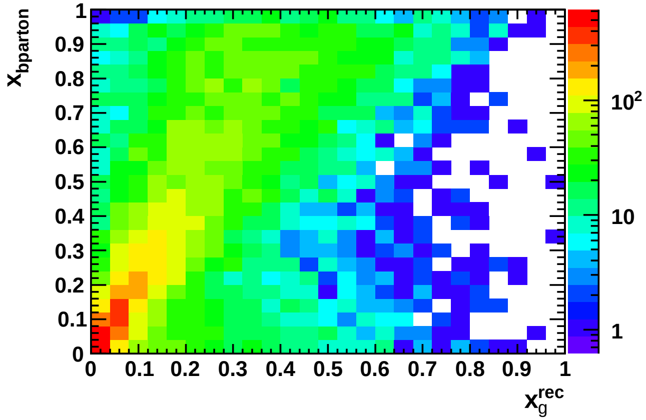


- **For both methods:**
  - **- At positive η_{LAB}, especially $\eta_{LAB} > 2$, the cross section is dominated by resolved process.**

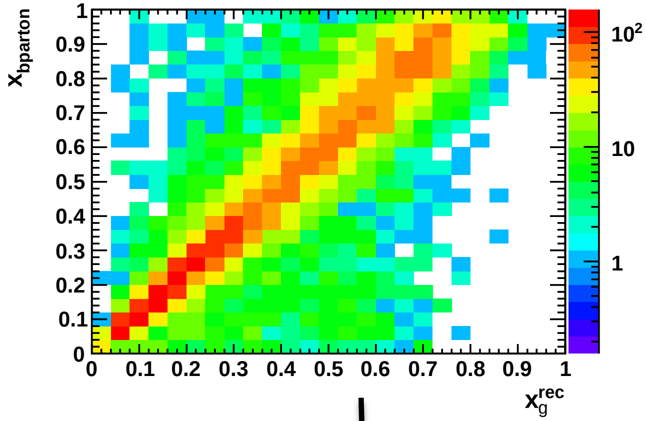
$\eta^{asso}{}_{LAB}$ distribution of associate hadron/jet shows the same results

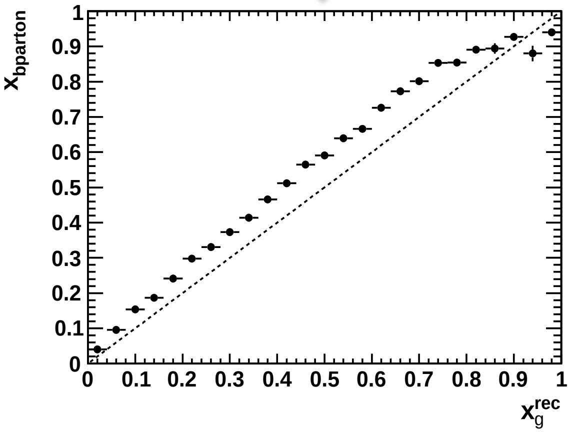
Reconstructing x^{rec}_{γ}

Di-hadron method



Di-jet method

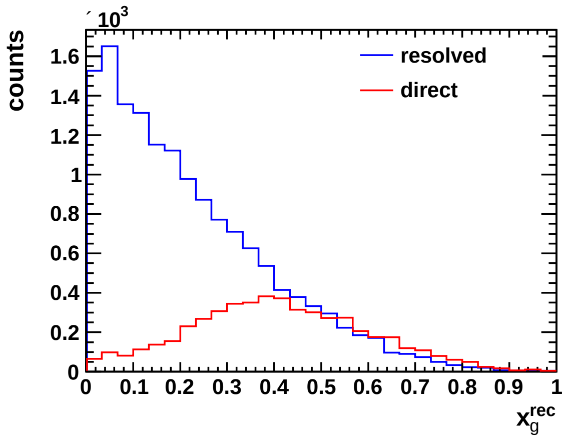




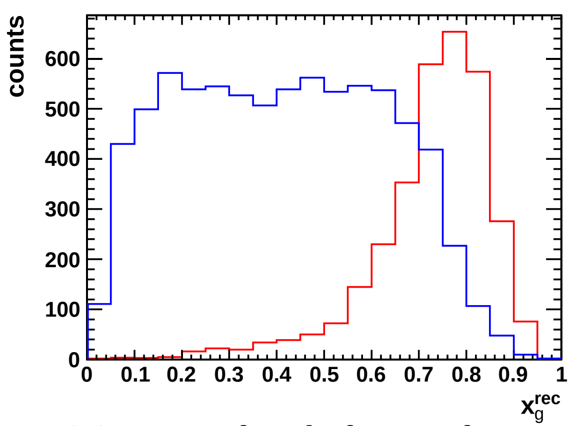
- **Both di-hadron and di-jet methods can help us separate resolved/direct process.**
- **Di-jet method provides a better way to reconstruct x^{rec}_{γ}**

$x^{rec}{}_{\gamma}$ separation

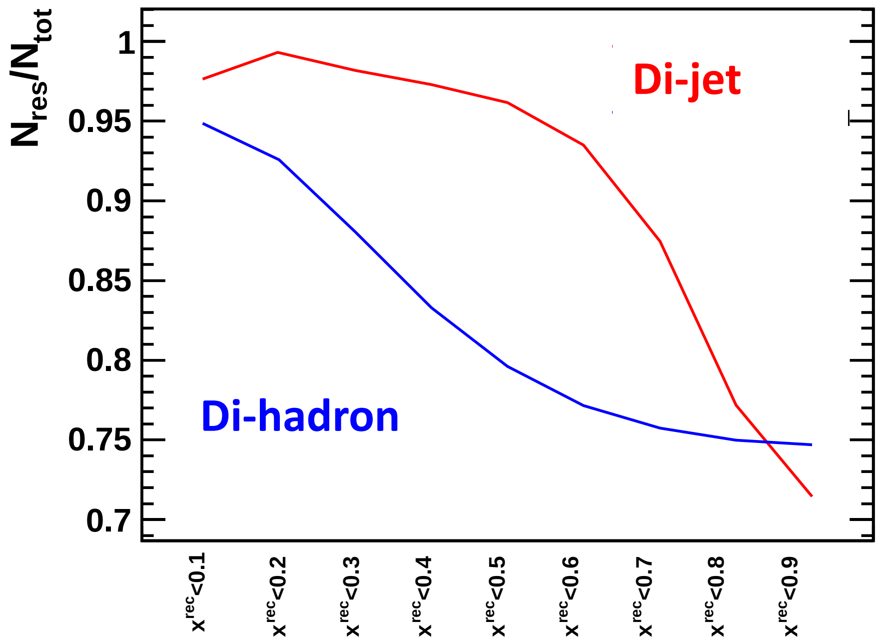
Di-hadron method



Di-jet method



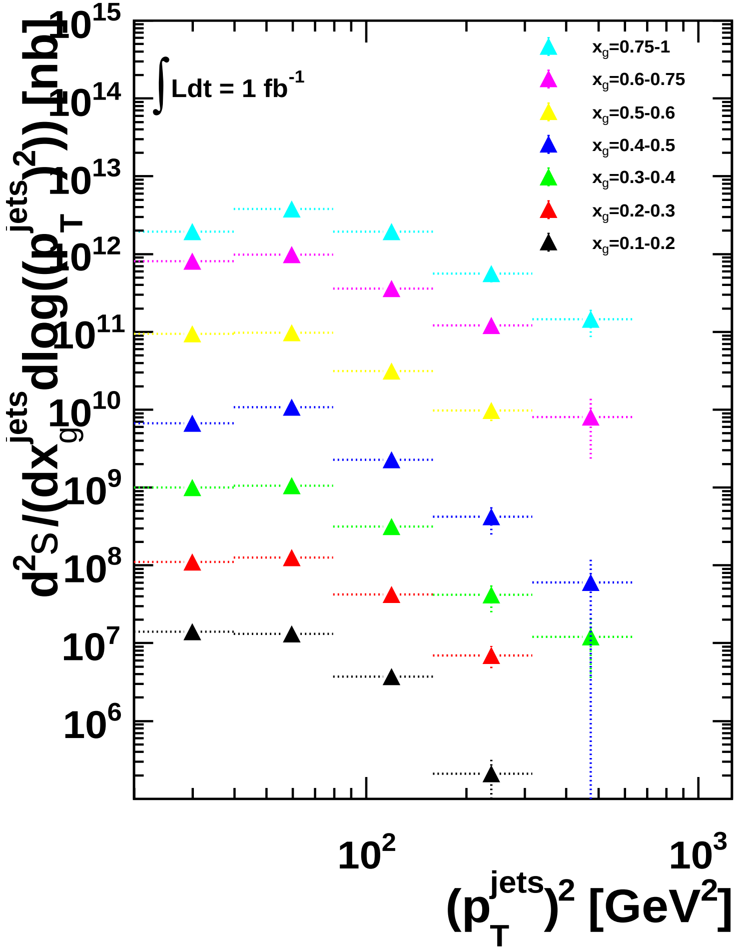
If we choose different $x^{rec}{}_{\gamma}$ cut, how well can we separate resolved/direct processes:



- **Small $x^{rec}{}_{\gamma}$: mainly resolved contribution**
- **Large $x^{rec}{}_{\gamma}$: mainly direct contribution**

- **Di-jet method shows better separation of resolved and direct photon**

Di-jet cross section

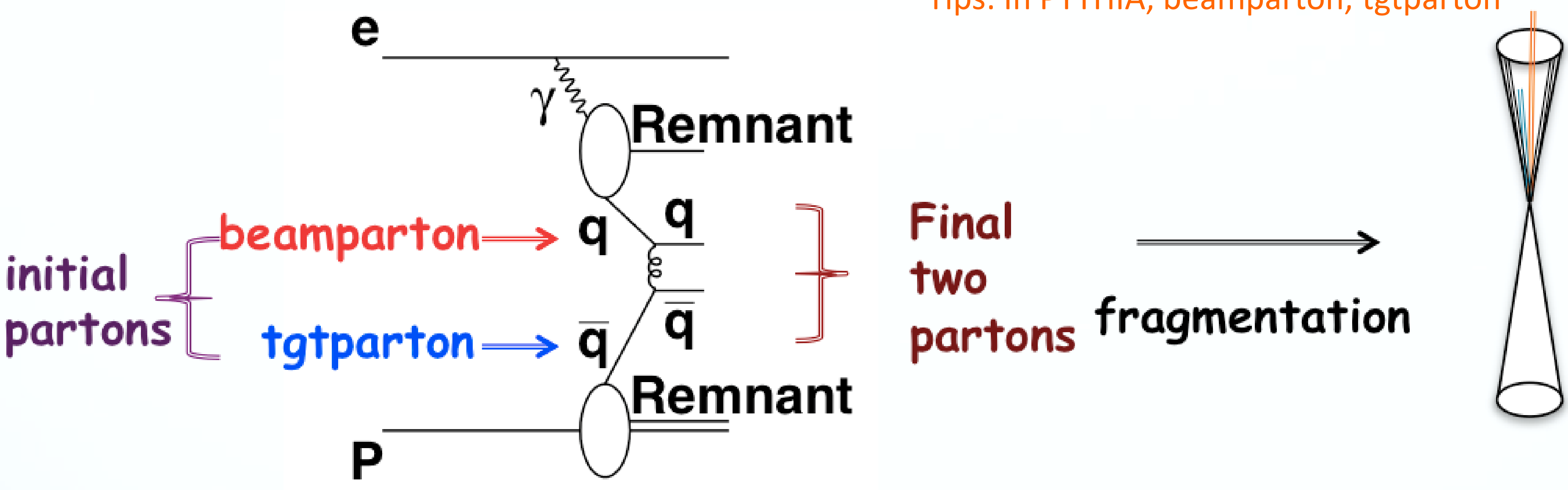


- The simulation shows the capability to measure the cross section for di-jet production, with high accuracy in a wide kinematic range at EIC and extract the photon PDFs from a global fit.

Parton-jet match

- As we have known how to separate "direct" and "resolved" process, then we measure jet kinematics in resolved process
- Basic info about resolved process and how to tag di-jet back to two final partons

Tips: In PYTHIA, beamparton, tgtparton

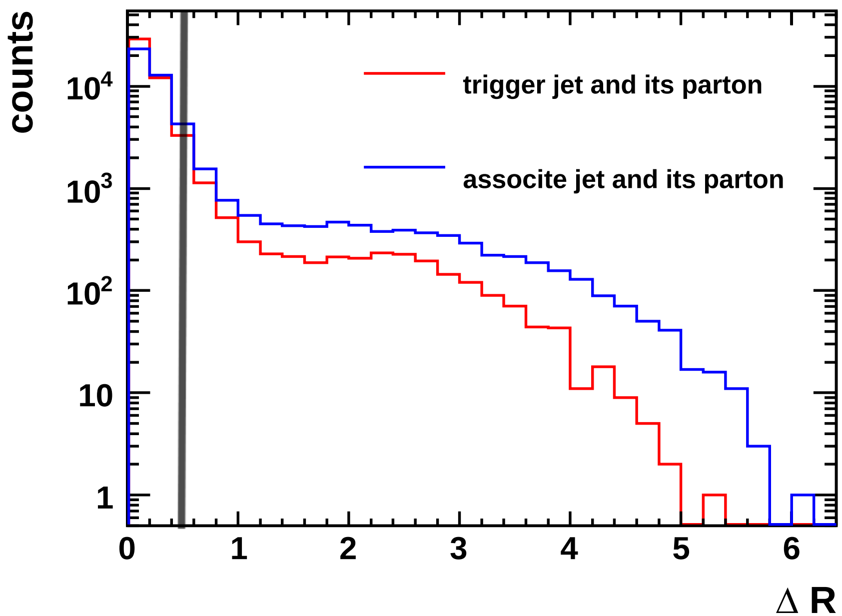


- **"Path" to do parton-jet match:**
  - beamparton - one final parton - one jet of di-jet → Jet from photon side
  - tgtparton - another final parton - another jet of di-jet → Jet from proton side

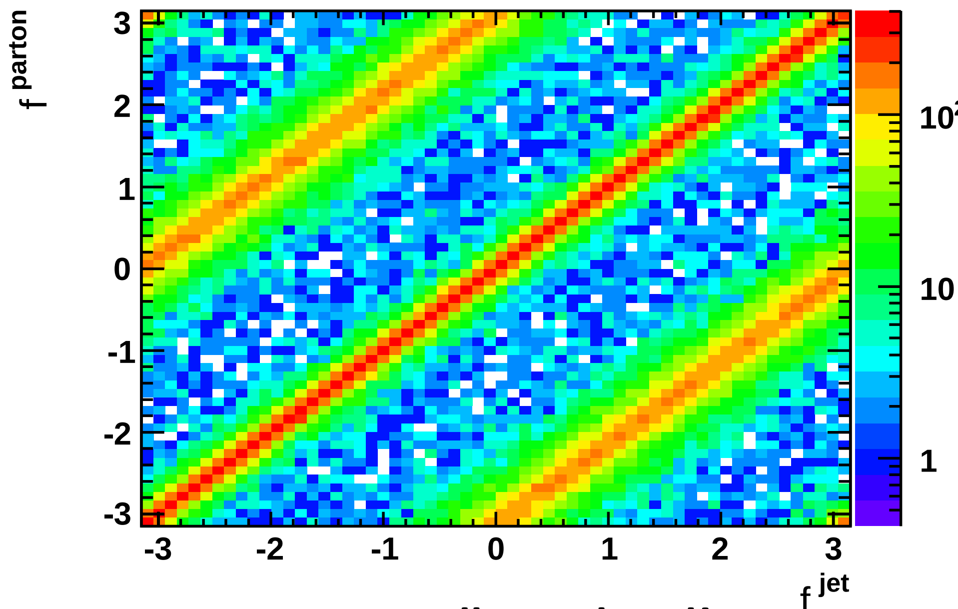
How to match di-jet with two final partons

Geometric match: $\Delta R\{parton - jet\} = \sqrt{\Delta\phi^2 + \Delta\eta^2}$

What I use $\Delta R\{parton - jet\} < 0.5$



If Pseudorapifity matches, what about the **angle correlation** between parton and jet:



Very well correlated!

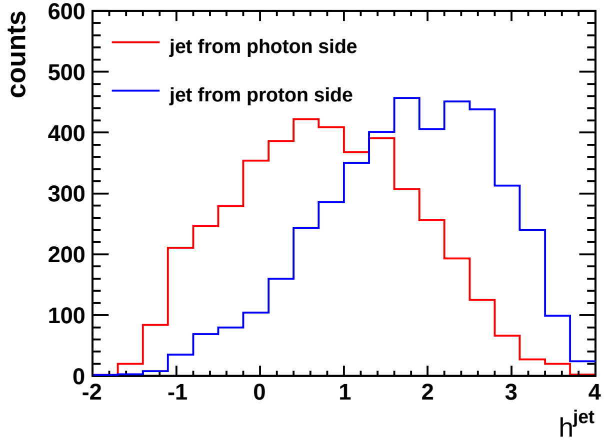
beamparton ✓ **match** → **Two final partons** ✓ **match** → **Di-jet**

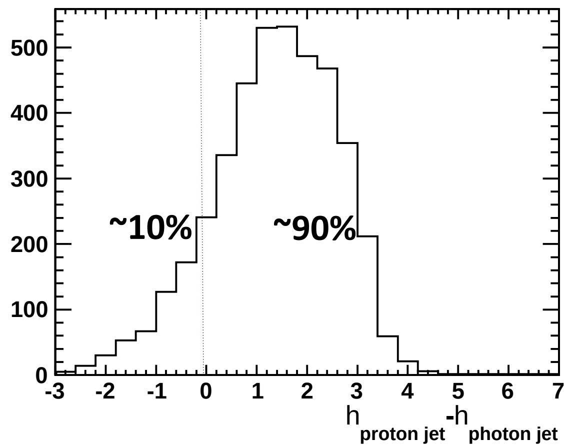
tgtparton

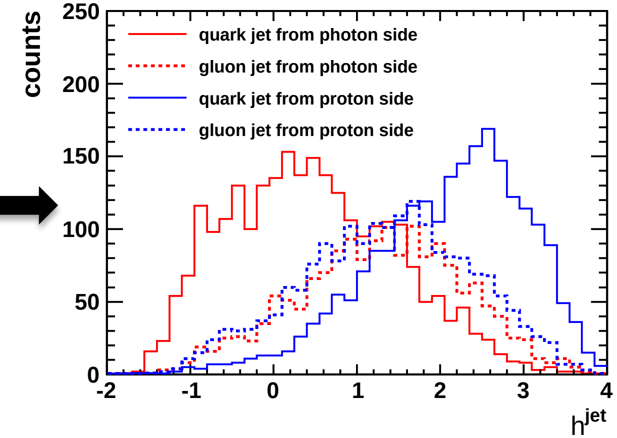
Photon side jet and proton side jet

hadrons $\eta_{LAB} > 0$ electrons $\eta_{LAB} < 0$

Separate jets from photon side and proton side

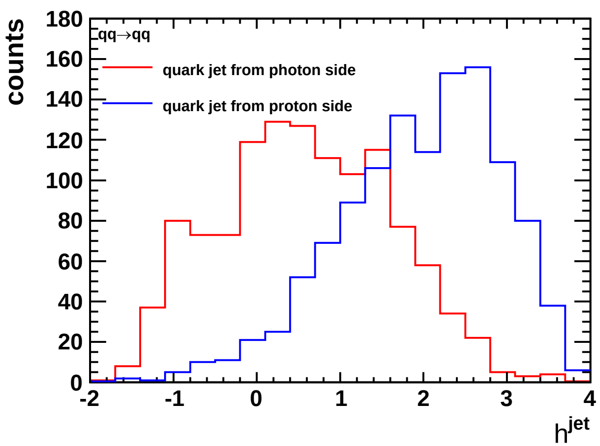




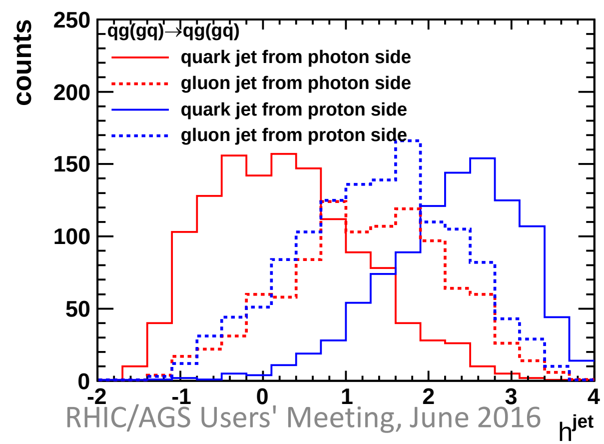


Divide into subprocesses

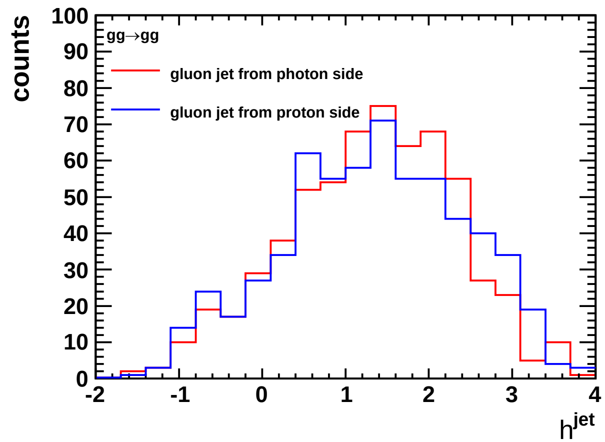
qq-qq 31.9%



gq(qg)-gq(qg) 55.8%



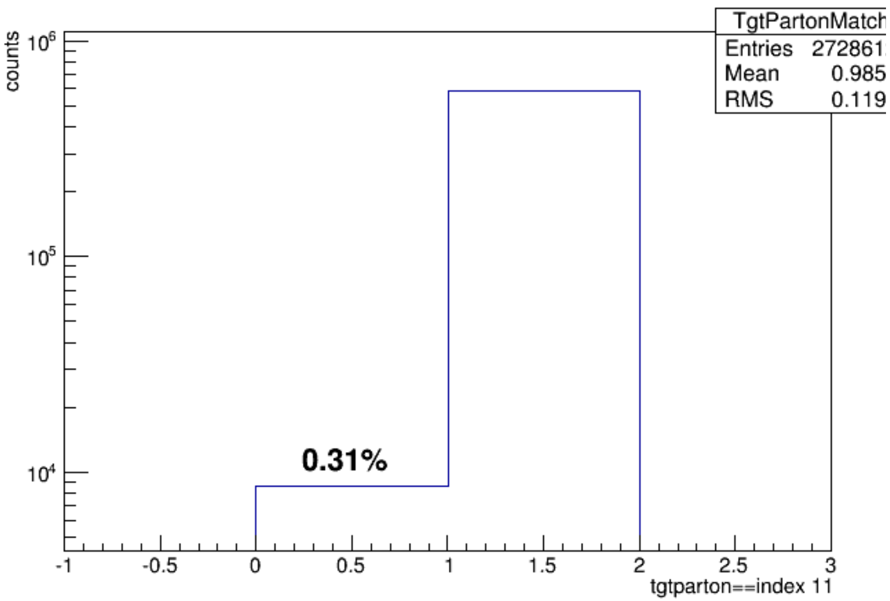
gg-gg 10.4%

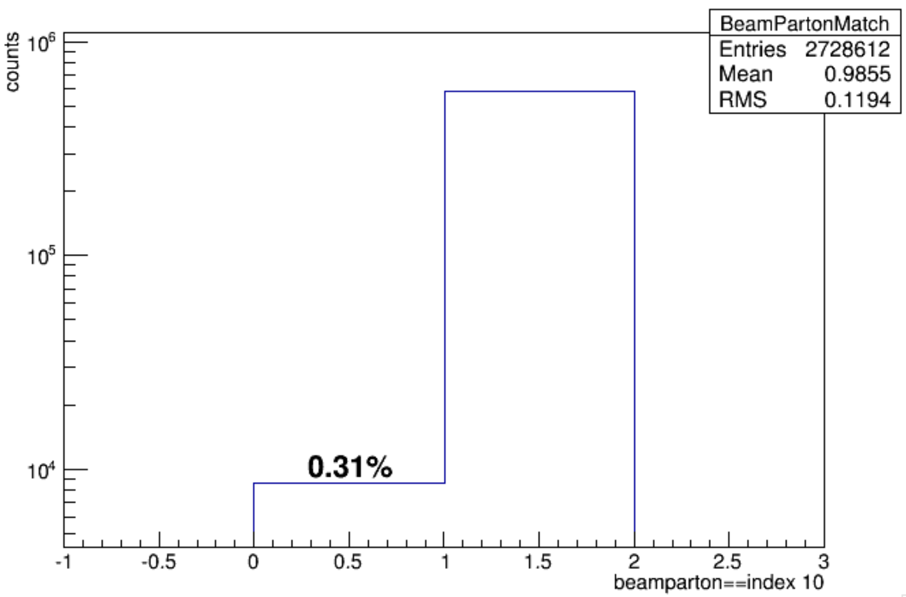


Summary

- **In resolved processes, photon has a hadronic structure**
  - Di-jets produced in resolved and direct process can be well separated at EIC
- **Photon PDFs can be extracted by reconstructing x_γ**
  - $x^{rec}{}_\gamma$ is correlated with input x_γ
  - We can effectively access the underlying photon PDFs by measuring di-jet cross section in quasi-real photoproduction at EIC
- **Jet from photon side goes more to negative rapidity**
  - Distinguish jets from beam side and target side
- **Will use LHC jet variables to separate gluon and quark jets statistically**

backup

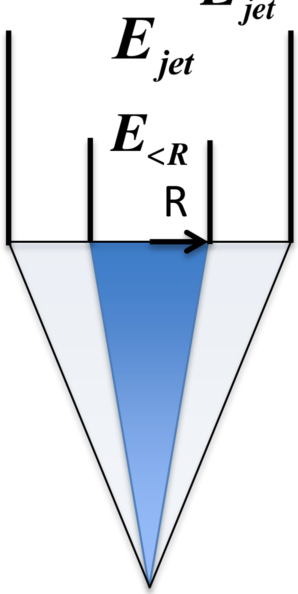


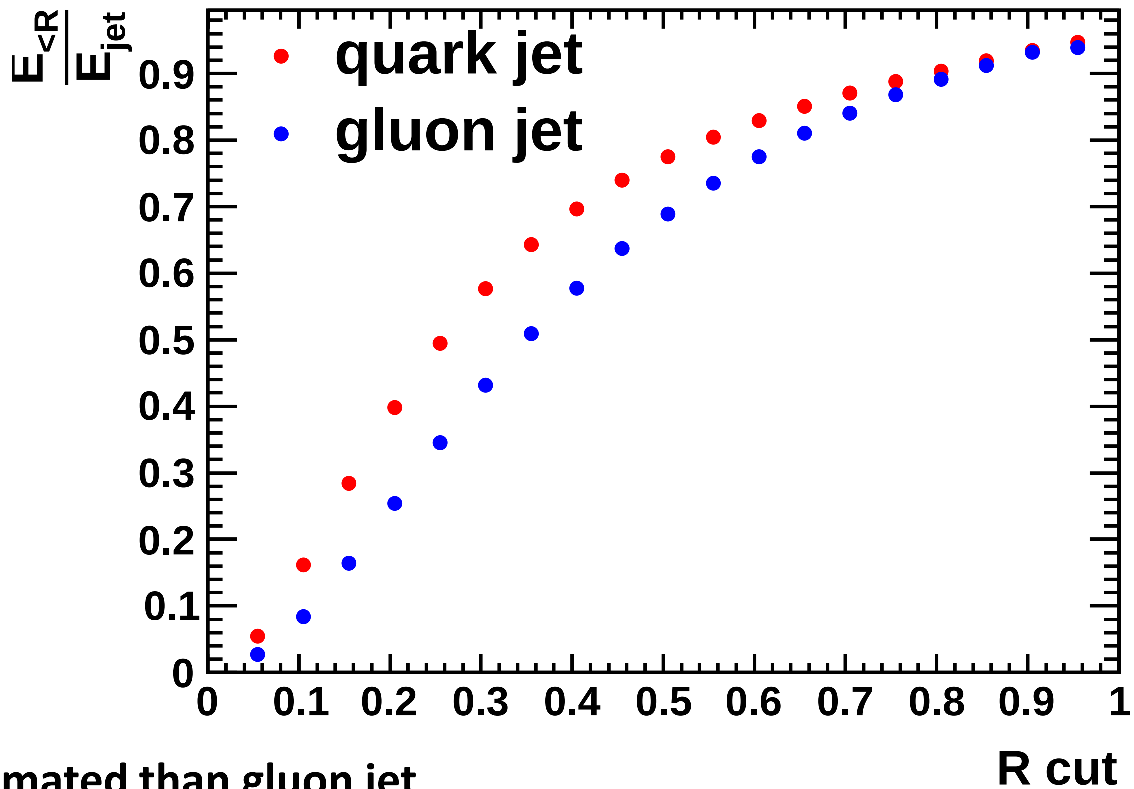


Flavor match: beamparton – index 9
tgtparton – index 10

Quark jet and gluon jet

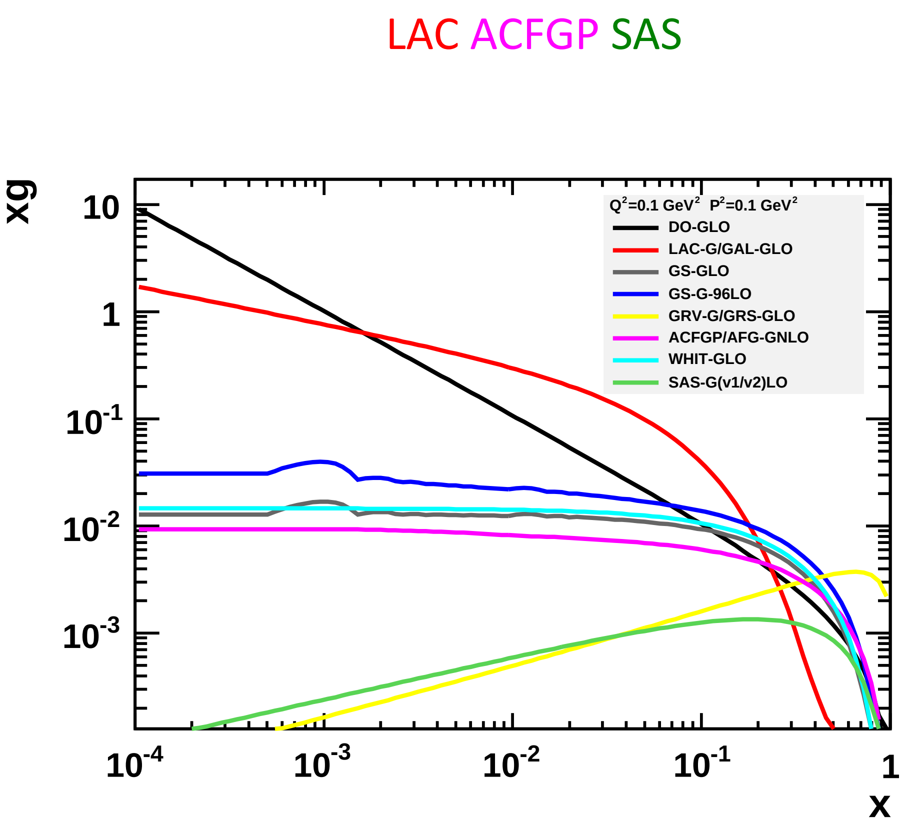
Jet profile: $\dfrac{E_{<R}}{E_{jet}}$



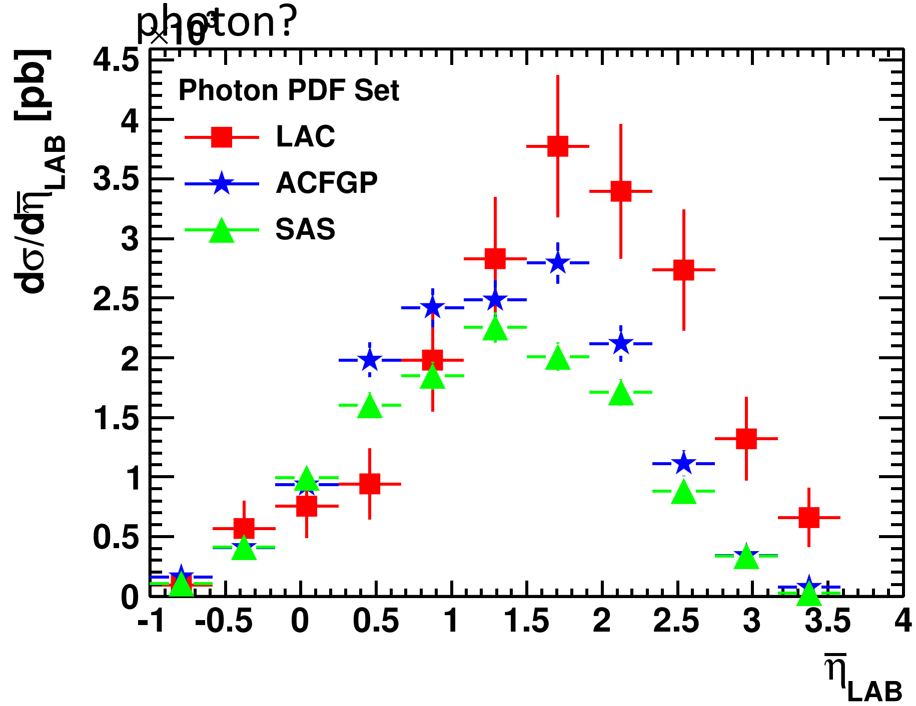


- **Quark jet is more collimated than gluon jet**
  - ➢ Choose a R cut with maximum difference value of jet profile, give possibility of types of jets

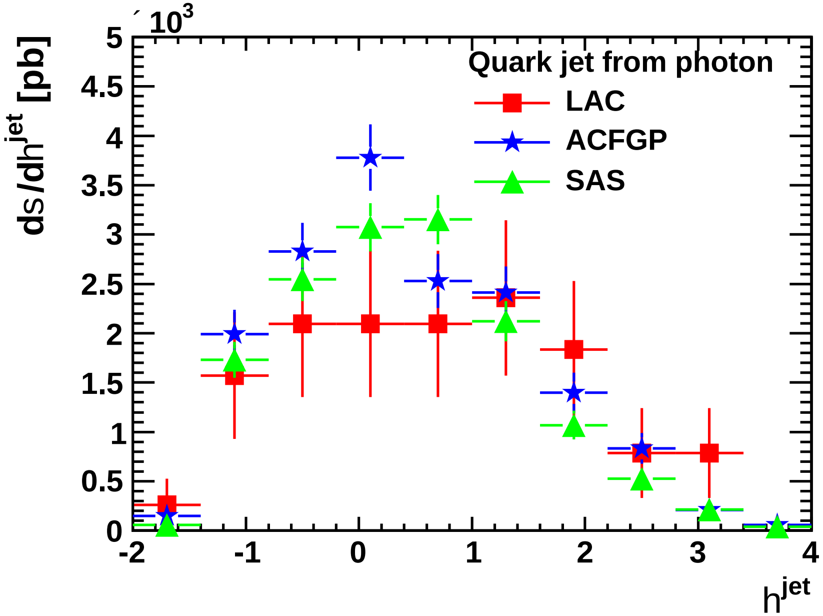
Di-jet cross section on different photon PDF sets

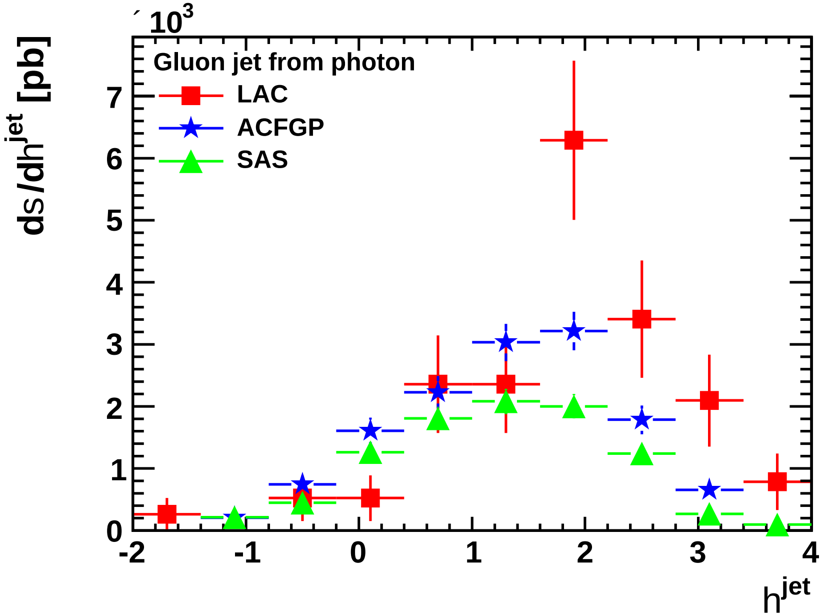


Question: Difference, especially when Pseudorapidity>1.5, maily comes from quark jet or gluon jet from the photon?



Di-jet cross section on different photon PDF sets





- **Answer:** It dominated by gluon jet if we only consider contribution from photon side jet.
- **Conclusion:** Gluon distribution of the photon is sensitive to di-jet cross section . Photon PDFs can be extracted by measuring the di-jet cross section in photoproduction process.